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Glenn contact:
Anthony C. Iannetti, 216–433–5586,
Anthony.C.Iannetti@nasa.gov

Author: Anthony C. Iannetti

Headquarters program office: OAT

Programs/Projects: Propulsion and Power, SEC, UEET, HPCCP

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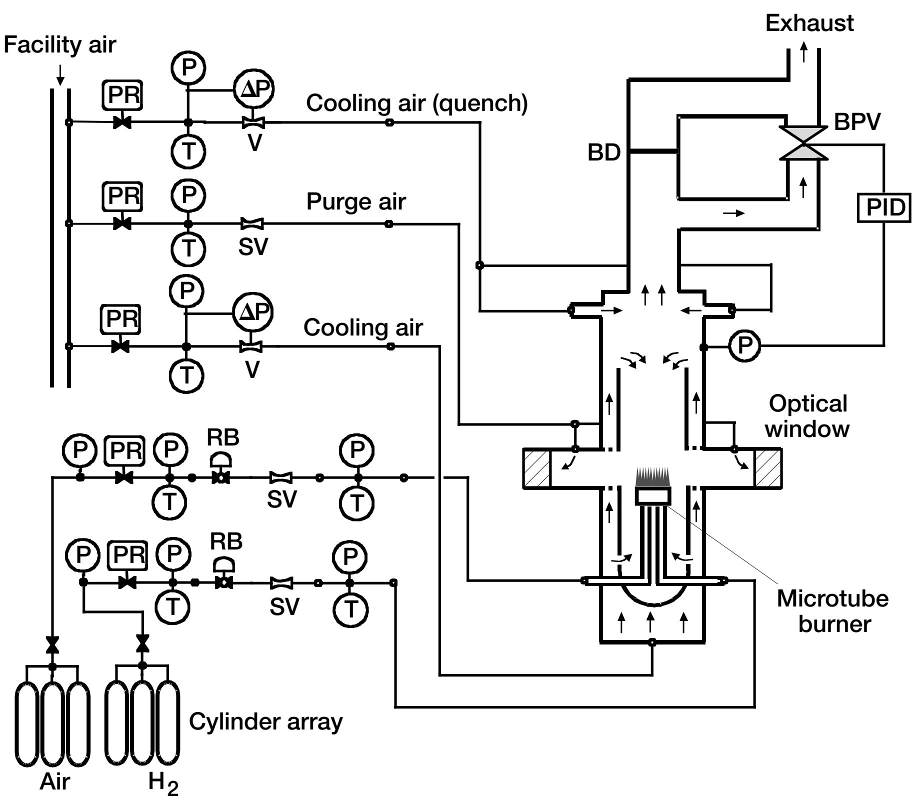
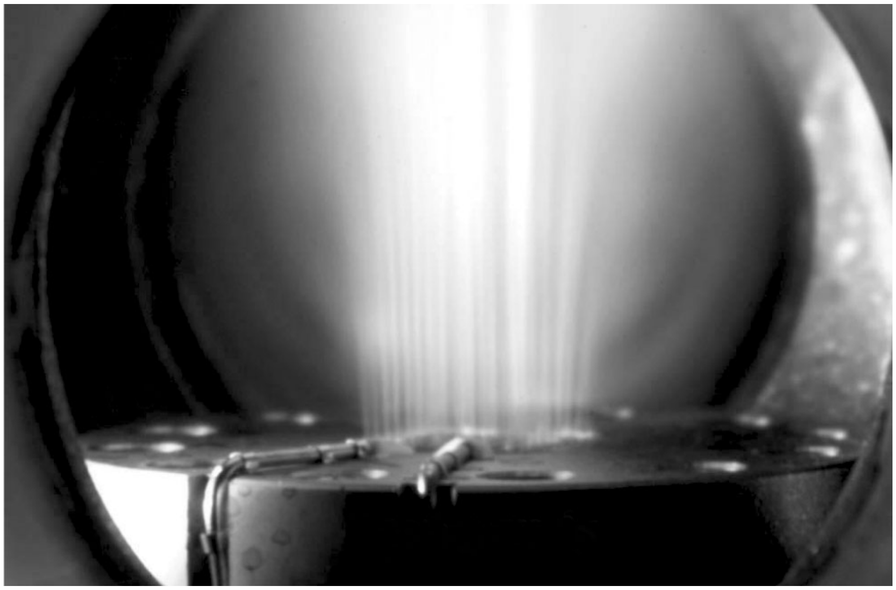
High-Pressure Gaseous Burner (HPGB) Facility Became Operational

A gas-fueled high-pressure combustion facility with optical access, developed over the last 3 years, is now collecting research data in a production mode. The High-Pressure Gaseous Burner (HPGB) rig at the NASA Glenn Research Center can operate at sustained pressures up to 60 atm with a variety of gaseous fuels and liquid jet fuel. The facility is unique because it is the only continuous-flow, hydrogen-capable 60-atm rig in the world with optical access. It will provide researchers with new insights into flame conditions that simulate the environment inside the ultra-high-pressure-ratio combustion chambers of tomorrow's advanced aircraft engines. The facility provides optical access to the flame zone through four fused-silica optical windows, enabling the calibration of nonintrusive optical diagnostics to measure chemical species and temperature. The data from the HPGB rig enable the validation of numerical codes that simulate gas turbine combustors.



High-pressure gaseous burner rig and gas flow system. P, pressure transducer; T, thermocouple; PR, remotely operated regulator; RB, remotely operated ball valve; V, venturi; SV, sonic venturi; BPV, back-pressure valve; PID, process controller; BD, burst disk.

This schematic shows the high-pressure burner rig and gas flow system. For pressures up to 30 atm, ambient-temperature air from the facility 450-psi compressor provides the 30-atm cooling air. For pressures above 30 atm, the cooling air is provided by a compressed-air tank array mounted on a trailer. The cooling air is introduced at the bottom of the rig for liner cooling (0.25 lbm/s maximum) and is introduced at the upper side as "quenching" airflow (0.20 lbm/s maximum). These airflows are controlled by remotely operated regulators using calibrated venturi flowmeters.



Photograph of a 20-atm hydrogen-air flame produced by the microtube burner in the HPGB facility operating at an equivalence ratio of 1.4. The diameter of the burner active region is approximately 0.75 in.

Approximately 10 percent or less of the total cooling flow rate of the facility air is used as purge flow for the optical windows during experiments to prevent water vapor condensation on the interior surfaces of the windows. The rig chamber pressure is regulated via a remotely controlled back-pressure valve mounted at the top of the chamber. A feedback-controlled process controller system stabilizes the chamber pressure to better than 1-percent accuracy for any given set point. For optical access, the burner rig has four ultraviolet-grade fused-silica windows with 44-mm-thick by 85-mm clear apertures located around the periphery of the flame zone. A burst disk (set at 935 psig) placed between the pressure chamber and facility exhaust pipe prevents overpressure conditions.

The specially designed microtube array burner is mounted inside the air-cooled high-temperature liner casing within the rig. The photograph shows the flame produced by the microtube burner at a pressure of 20 atm and an equivalence ratio of 1.4. The burner was designed to provide a uniform combustion product zone downstream of the flame for calibrating the laser Raman diagnostic system. The oxidizer air and the hydrogen fuel are provided by 12-pack cylinder arrays at a nominal pressure of 150 atm. The flow rates of the air and fuel can be precisely controlled with better than 0.5-percent accuracy using sonic venturi flowmeters in conjunction with computer-operated pressure regulators and valves. The flows can be adjusted to vary the flame's equivalence ratio ϕ from about 0.3 (very fuel-lean) to 4 (fuel-rich), providing a wide span of combustion products in the flame zone for optical diagnostics calibration. The maximum fuel flow rate is limited by the cooling capacity of the facility (400 000 Btu/hr). For the current series of experiments, only hydrogen-air mixtures are required; however, the facility is designed to accommodate different fuels and oxidizers including carbon monoxide, methane, oxygen-argon, and pure oxygen. All aspects of the facility operation, including startup, shutdown, and automatic safety shutdowns are controlled and monitored via an icon-based touch-screen software system and a programmable logic controller in conjunction with a cost-effective four-PC server cluster.

Glenn contacts:
Dr. Quang-Viet Nguyen, 216–433–3574, Quang-Viet.Nguyen-1@nasa.gov;
William K. Thompson, 216–433–2638, William.K.Thompson@nasa.gov,
Gary V. Lorenz, 216–433–5996, Gary.V.Lorenz@nasa.gov; and
Paulette E. Adams, 216–433–5237, Paulette.E.Adams@nasa.gov

National Research Council contact:
Dr. Jun Kojima, 440–962–3095, Jun.Kojima@grc.nasa.gov

QSS Group, Inc., contact:
Gregg Calhoun, 216–433–5782, Gregory.G.Calhoun@grc.nasa.gov

Akima Corp. contact:
Raymond C. Lotenero, 216–433–2849, Raymond.C.Lotenero@grc.nasa.gov

Author: Dr. Quang-Viet Nguyen

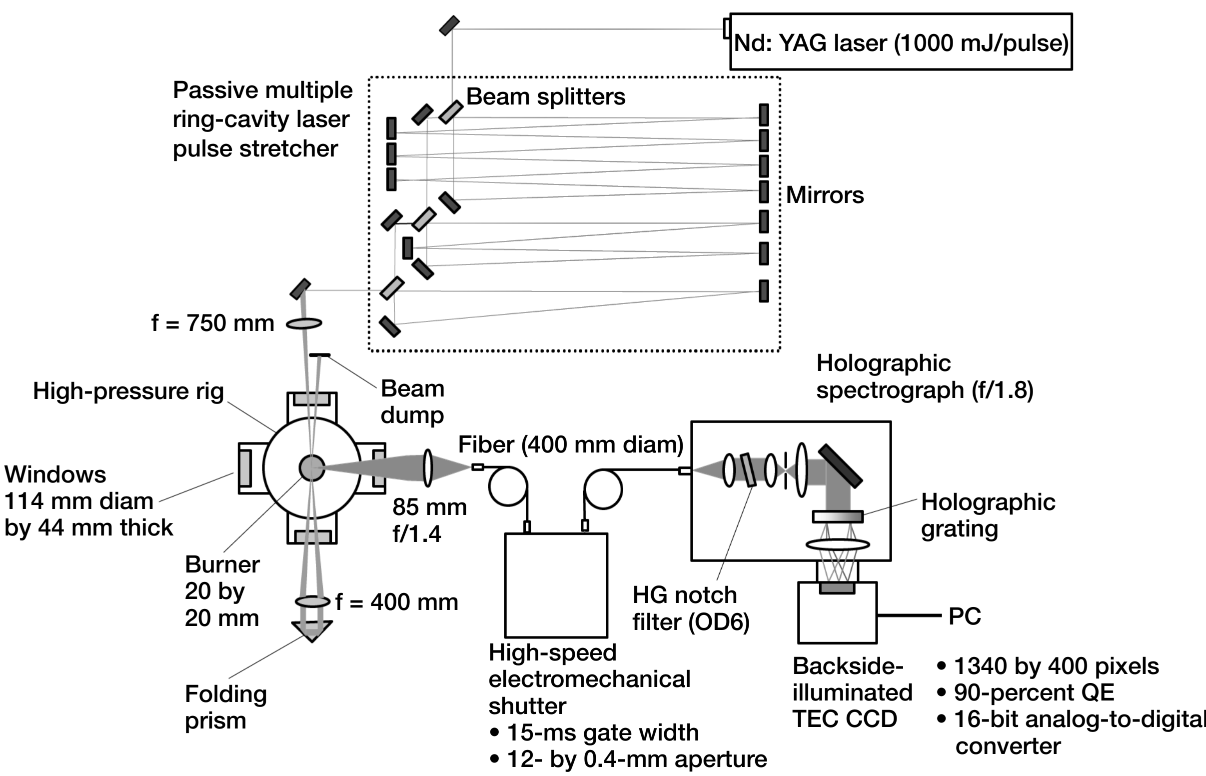
Headquarters program office: OAT

Programs/Projects: UEET, ZCET, SEC

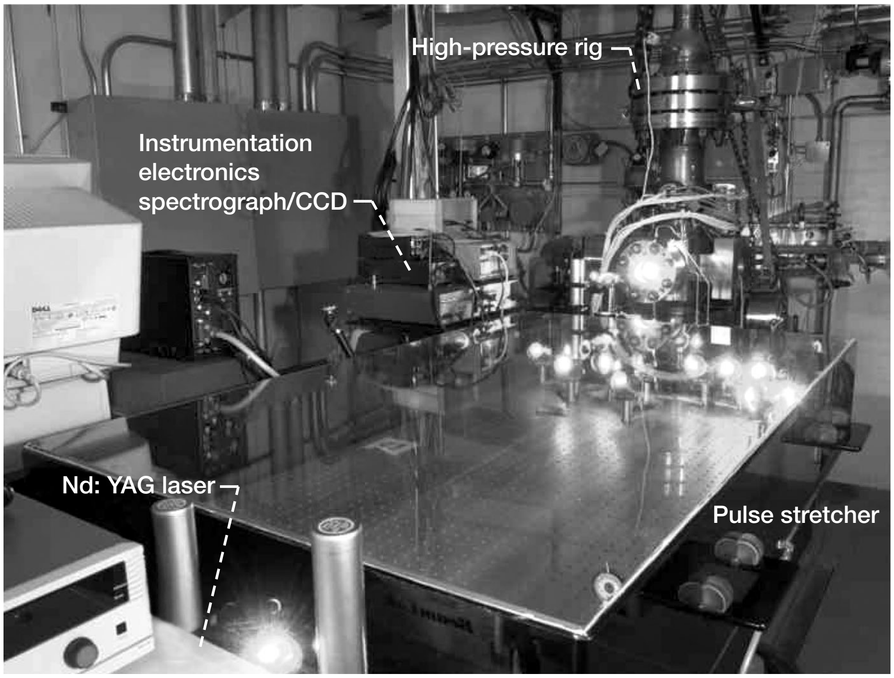
Spontaneous Raman Scattering (SRS) System for Calibrating High-Pressure Flames Became Operational

A high-performance spontaneous Raman scattering (SRS) system for measuring quantitative species concentration and temperature in high-pressure flames is now operational. The system is located in Glenn's Engine Research Building. Raman scattering is perhaps the only optical diagnostic technique that permits the simultaneous (single-shot) measurement of all major species (N_2, O_2, CO_2, H_2O, CO, H_2, and CH_4) as well as temperature in combustion systems. The preliminary data acquired with this new system in a 20-atm hydrogen-air (H_2-air) flame show excellent spectral coverage, good resolution, and a signal-to-noise ratio high enough for the data to serve as a calibration standard. This new SRS diagnostic system is used in conjunction with the newly developed High-Pressure Gaseous Burner facility (ref. 1). The main purpose of this diagnostic system and the High-Pressure Gaseous Burner facility is to acquire and establish a comprehensive Raman-scattering spectral database calibration standard for the combustion diagnostic community. A secondary purpose of the system is to provide actual measurements in standardized flames to validate computational combustion models. The High-Pressure Gaseous Burner facility and its associated SRS system will provide researchers throughout the world with new insights into flame conditions that simulate the environment inside the ultra-high-pressure-ratio combustion chambers of tomorrow's advanced aircraft engines.

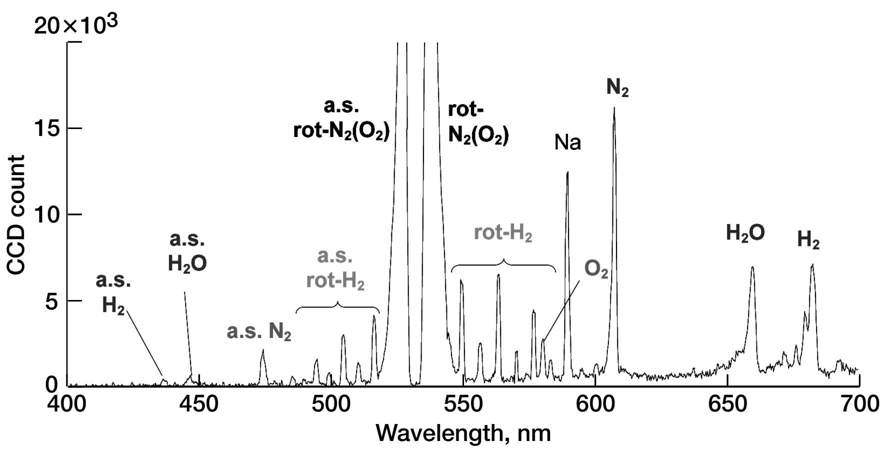
The schematic shows the SRS system, and the photograph on the next page shows the system in operation. The SRS system was designed in-house by Dr. Quang-Viet Nguyen of



High-performance SRS system. The output of a frequency-doubled pulsed Nd:YAG (neodymium-doped yttrium aluminum garnet) laser (532 nm) is temporally stretched using a passive three-cavity optical delay line. The stretched laser output (1000 mJ over 80 ns) is then focused into the measurement zone inside the high-pressure rig. The Raman-scattered light (signal) is collected perpendicular to the excitation laser beam and fiber-optically coupled into a high-speed electromechanical shutter system to reject background luminosity. The output of the shutter system is fiber-optically coupled to a high-speed holographic spectrograph fitted with a thermoelectrically cooled backside-illuminated charge-couple device (CCD) camera. The CCD camera images are processed by computer to yield the Raman-scattering spectrum. The spatial resolution of the probe volume is approximately 1.4 by 0.5 mm. (HG, holographic grating; OD6, optical density 6 (provides a 6-order magnitude attenuation in optical intensity); TEC, thermoelectrically cooled; QE, quantum efficiency (efficiency of detecting a single photon).)



Photograph of the SRS diagnostic system in the High-Pressure Gaseous Burner facility. The bright green light scattered from the pulse stretcher mirrors is the 532-nm wavelength excitation laser light. This figure is shown in color in the online version of this article (http://www.grc.nasa.gov/WWW/RT2002/5000/5830nguyen2.html).

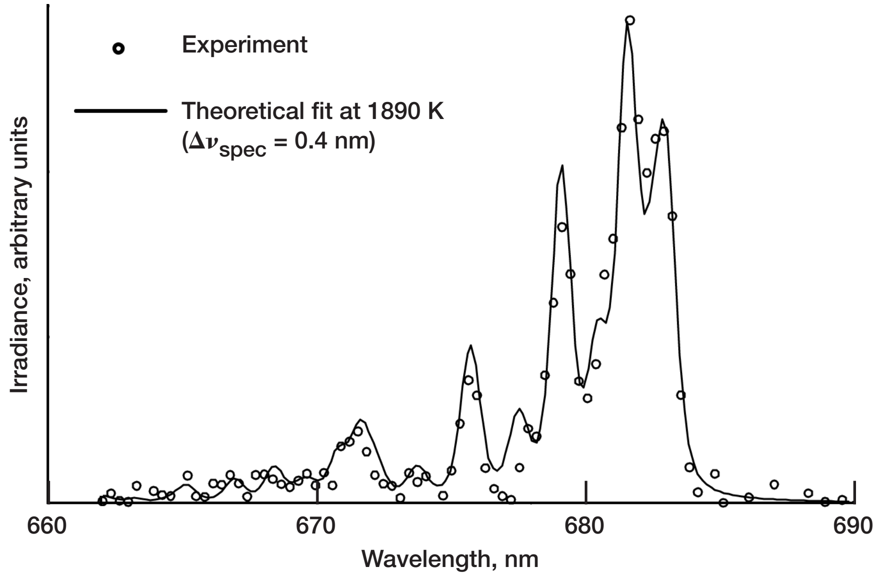


SRS spectrum of a H_2-air flame at a rig pressure of 20 atm and an equivalence ratio of 1.4. The spectrum was averaged over 250 laser shots and collected at a low spectral resolution of 40 cm^{-1}. The entire visible spectrum from 400 to 700 nm can be captured in a single spectrum, enabling the simultaneous quantitative determination of species temperature and concentration (a.s., anti-Stokes; rot, rotational).

Glenn's Combustion Branch and built with the help of Dr. Jun Kojima (National Research Council Research Associate) and Raymond Lotenero (Akima Corp.). Many strategies and techniques are employed to maximize the weak Raman signal, including a high-pulse-energy (1000-mJ/pulse) laser, a pulse stretcher to avoid damaging the optical windows, a laser beam that is folded back through the probe volume to double the energy, high-speed optics and spectrograph to maximize collection efficiencies, and a custom-designed electromechanical shutter and backside-illuminated charge-coupled device (CCD) camera to achieve 90-percent quantum efficiency.

The following graph shows the SRS spectrum of a H_2-air flame at a rig pressure of 20 atm and an equivalence ratio of 1.4. The two large features centered at 532 nm are the pure-rotational Raman features of nitrogen (N_2) and some oxygen (O_2). The spectral features to the left of the excitation wavelength (532 nm) are the anti-Stokes-shifted Raman-scattering signals, whereas the features to the right are the Stokes-shifted Raman-scattering signals. Both the shape of the spectral features and the ratio of Stokes to anti-Stokes signals permit temperature measurement with about 50-K accuracy. The amplitudes of the peaks enable major species concentration determination with about 2 mol% accuracy. Correlating the measured Raman signal response with chemical equilibrium predictions based on measured reactant flow rates allows one to map out a quantitative calibration of the SRS signals versus interferences. This process is repeated for many different flame conditions, different flame reactants, and different pressures.

We have also developed a comprehensive theoretical Raman-scattering model for all the major species in hydrocarbon-air. As an example, the figure on the next page shows a theoretically calculated vibration-rotation Raman spectrum of H_2 compared with experimental data. The data were obtained at a spectral resolution of 10 cm^{-1} in a 20-atm H_2-air flame at an equivalence ratio of 1.4. The fitted temperature of 1890 K derived from the spectral shape is consistent with the temperature derived from both the pure-rotational spectrum of H_2 and the vibration-rotation spectrum of N_2.



Comparison of a comprehensive theoretical model of Raman scattering that includes the effects of pressure broadening with the experimentally measured vibration-rotation Raman spectrum of H_2 at a pressure of 20 atm in a 20-atm H_2-air flame; $\Delta\nu_{spec}$, spectral resolution of the spectrograph.

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Find out more about the research of Glenn's Combustion Branch:
http://www.grc.nasa.gov/WWW/combustion/

Glenn contact:
Dr. Quang-Viet Nguyen, 216–433–3574, Quang-Viet.Nguyen-1@nasa.gov

Author: Dr. Quang-Viet Nguyen

Headquarters program office: OAT

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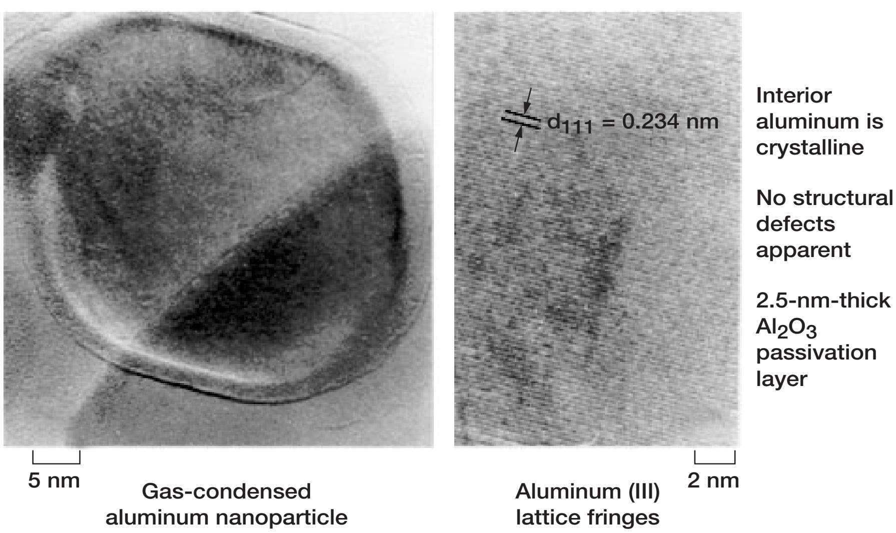
Nanotechnology Investigated for Future Gelled and Metallized Gelled Fuels



Typical aluminum nanoparticle created by Technanogy, Inc., with an aluminum vaporization process. The particles are from 20 to 100 nm in diameter. The interior aluminum is crystalline. No structural defects are apparent. There is a 2.5-nm-thick Al_2O_3 passivation layer. (Copyright Los Alamos National Laboratory; used with permission.)

The objective of this research is to create combustion data for gelled and metallized gelled fuels using unique nanometer-sized gellant particles and/or nanometer-sized aluminum particles. Researchers at the NASA Glenn Research Center are formulating the fuels for both gas turbine and pulsed detonation engines. We intend to demonstrate metallized gelled fuel ignition characteristics for pulse detonation engines with JP/aluminum fuel and for gas turbine engines with gelled JP, propane, and methane fuel.

The fuels to be created are revolutionary as they will deliver the highest theoretically maximum performance of gelled and metallized gelled fuels. Past combustion work has used micrometer-sized particles, which